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EXPERIMENTAL INVESTIGATION OF MOISTURE VAPOR TRANSMISSION THROUGH TENTAGE FABRICS

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13. ABSTRACT *(Maximum 200 words)*

In order to test the validity of a theoretical model of agent transfer through a fabric membrane and to develop a standardized method for testing infiltration through fabrics under steady wind and external conditions, an experimental apparatus and procedure have been developed using water vapor as a tracer. This experimental model is capable of measuring infiltration through a fabric membrane into a test cylinder under a variety of external wind speeds and internal overpressures. Experiments have been conducted on cotton duck, cotton oxford, and polyester duck. The data collected will be used to verify the results of the theoretical model and to compare the infiltration rates of different fabrics under a variety of conditions.

A comparison of initial predictions made using the theoretical model with experimental results revealed that there was a slower rate of infiltration into the chamber in the experiments than was predicted by the theoretical model. It is thought that this difference is due to the fact that the computational code models the fabric as a membrane with constant properties, while in the experiment its properties are changing. For example, as the fabric absorbs moisture and the fibers swell, the permeability of the fabric is decreased.

14. SUBJECT TERMS

TENTAGE, FABRICS, WATER VAPOR, INFILTRATION, MODELS, MOISTURE VAPOR TRANSMISSION, WIND TUNNEL TESTS, WIND TUNNEL MODELS, AGENT TRANSFER

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PREFACE

The work described in this report on an experimental apparatus and procedure capable of measuring moisture vapor transmission through fabrics was undertaken during the period October 1989 to September 1991. The funding was program element 62786A, Project No. 1L162786A47, Task No. BO, and Work Unit Accession No. BOO.

The work was performed by Gary Vincens and Kyle Welch in the Engineering Technology Division of the Aero-Mechanical Engineering Directorate. The testing apparatus was designed by Struan Robertson of the University of Lowell and Clive Nickerson of the Engineering Technology Division.

EXPERIMENTAL INVESTIGATION OF MOISTURE VAPOR TRANSMISSION THROUGH TENTAGE FABRICS

Introduction

The ability to study infiltration of airborne contaminants under constant wind conditions is of extreme importance when dealing with chemical or biological agents. A numerical method of determining agent infiltration into structures would allow the study of new shelter designs at a significant cost savings over live-agent testing. A two-dimensional finite difference code to predict infiltration rates through woven screens for both laminar and turbulent external flows was developed.[1]

In order to verify this code and to generate data which can be used to improve the code's accuracy, an experimental apparatus has been designed and constructed which is capable of studying infiltration rates through fabrics under a variety of external and internal conditions using water vapor as a tracer. A test chamber with a fabric endcap is located concentrically within a laboratory wind tunnel with a circular cross-section. The chamber can be internally pressurized to determine the effect of overpressure on the moisture vapor transfer rate.

The results of these experiments can then be used to develop empirical relations for different fabrics which will be incorporated into the computer code to form a more accurate model. The primary fabrics studied are uncoated specimens of cotton duck, cotton oxford, and polyester duck. Due to safety considerations and ease of measurement, the experimental apparatus uses water vapor as a tracer gas. By varying wind speed and chamber overpressure, data are obtained which provide moisture transfer rates for a variety of environmental conditions.

Another potential use for this apparatus is as a standard testing method for fabrics under a variety of conditions. By conducting experiments under a variety of conditions, the different mechanisms of transport through the fabric can be examined to determine which are most affected by varying the conditions of the experiment. Results from these experiments were found to be reproducible and consistent for the sample fabrics studied. The user would be able to determine the rate which a contaminant is transferred through a fabric for given environmental conditions.

Description/Setup

Wind Tunnel and Instrumentation

Experiments to determine the infiltration rate of water vapor at various overpressures were carried out on a benchtop wind tunnel shown in Figure 1. The tunnel consists of two,

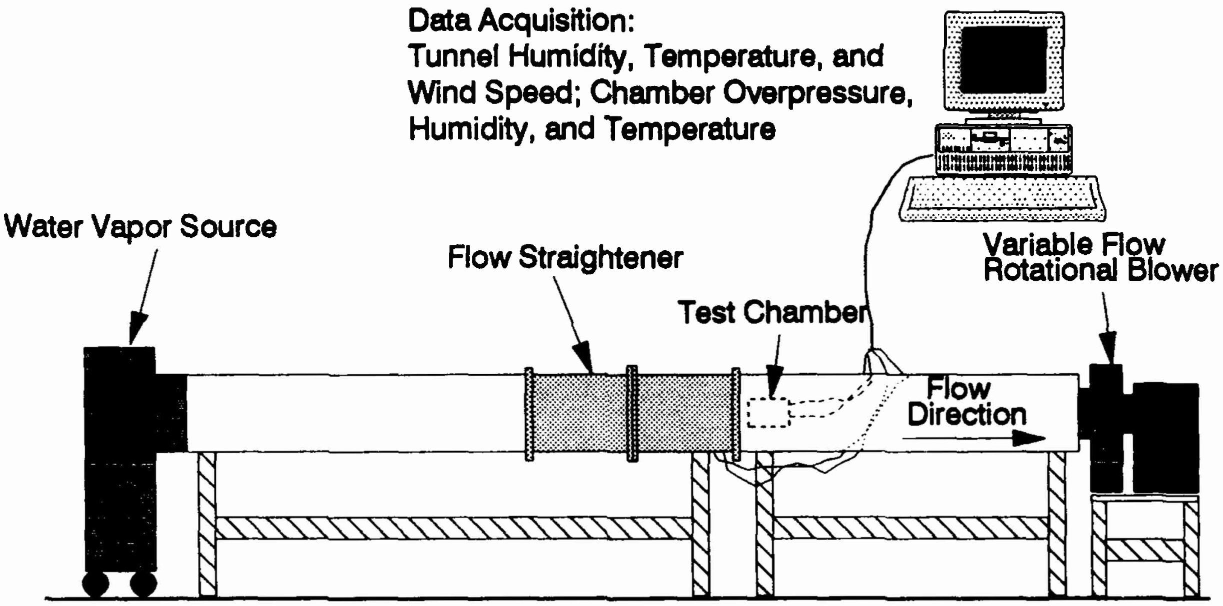

Figure 1. Wind Tunnel apparatus for moisture vapor transmission experiments.

5-feet by 8-inch inner diameter sections of polyvinyl chloride (PVC) pipe joined together with a flow meter. The flow meter uses an averaging Pitot tube arrangement to supply the high- and low-pressures for the tunnel wind velocity calculation. The flow meter contains honeycomb which serves to straighten the flow before it encounters the test chamber. The test chamber is located just downstream of the honeycomb, where the flow is the least disturbed. (See Appendix A for a schematic of the flow meter)

The test chamber is fastened concentrically within the tunnel by three radial supports as shown in Figure 2. The fabric sample is held over the open-end of the test chamber by a hose clamp fitted over the outside of the chamber. The fabric is placed over the open-end of the test chamber and then pulled outward to remove wrinkles in the fabric. Care is taken not to stretch the fabric and distort its shape as this would modify the natural weave of the fabric and change the air-flow resistance of the material.

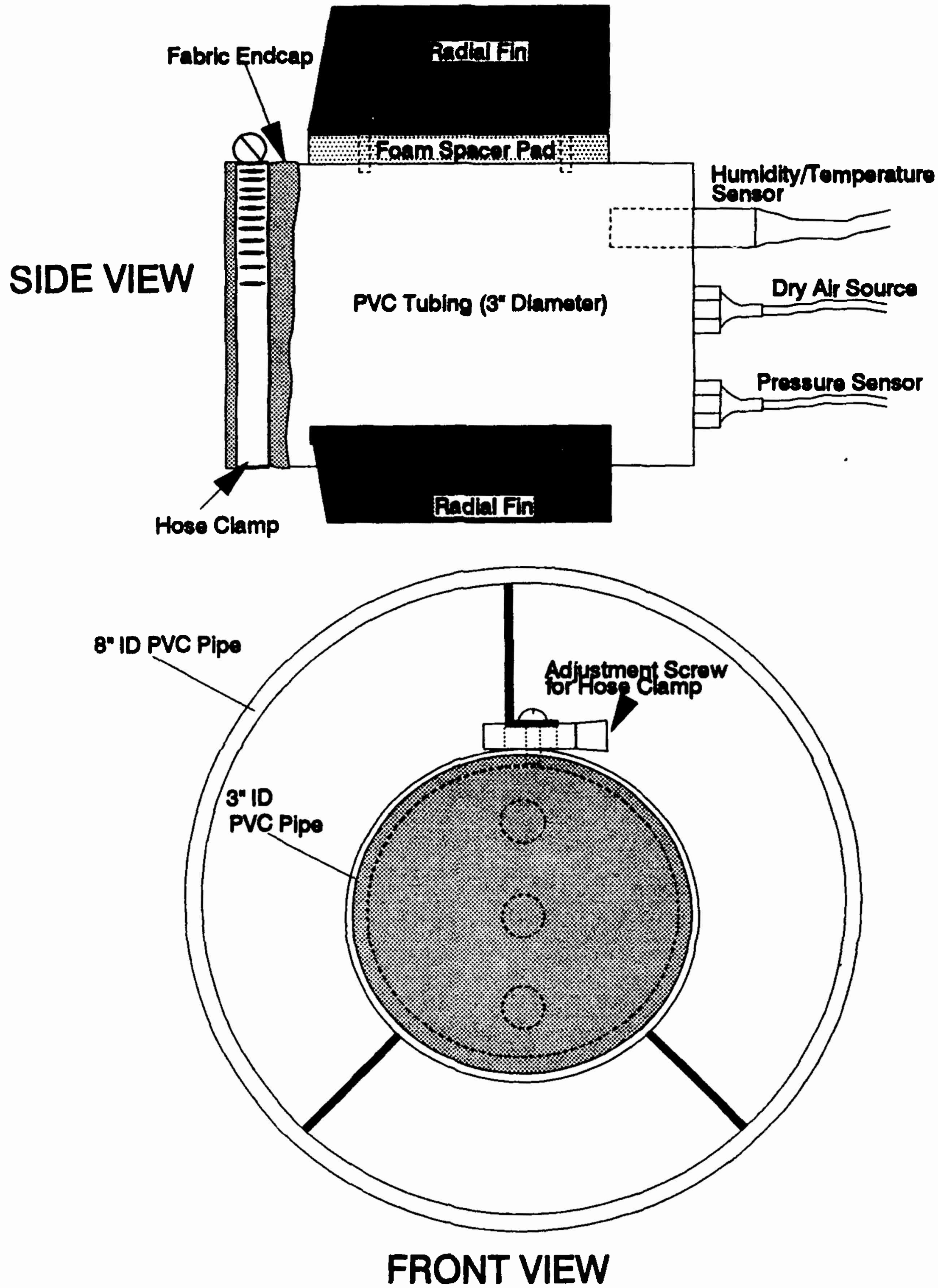

Figure 2: Side and front view of test chamber.

The test chamber shown in Figure 2 is 3-inches long and is constructed from 3-inch inner diameter PVC pipe, sealed at one end with a flat piece of PVC. The sealed end has holes in it for the dry air inflow line, the pressure sensor line, and the temperature/humidity probe, all of which fit tightly so that no air is able to leak into the chamber around them. The air used to pressurize the chamber is compressed, then run through a flask containing calcium chloride to further remove moisture from the air. The level of overpressure in the chamber is controlled by a flow meter on the airline between the flask containing the calcium chloride and the test chamber.

After being dried using the calcium chloride, the air entering the test chamber has a relative humidity (RH) ranging from 14 to 16 percent RH and a temperature ranging from 68°-72°F. The ambient humidity in the room is highly dependent on the atmospheric conditions, and ranged from 14 to 40 percent RH. The ambient room conditions are significant as they affect the initial conditions within the tunnel and the test chamber. The humidifier draws dry air directly from the room, so the properties of the room air will have an effect on the quality of the moist air discharged by the humidifier. Experiments determined that the data generated became inaccurate when the room humidity was greater than 35 percent RH. For this reason data corresponding to ambient room humidities of 25 percent RH or less were used for comparison purposes.

To maintain stable ambient conditions in the room, several climate-adjusting devices are used. Two electric, portable heaters and a water-cycle air conditioner are used to stabilize the temperature in the room during warm and cold periods, while two portable dehumidifiers were used to maintain constant ambient humidity during the tests.

The flow in the tunnel is generated using a 500 cfm rotational blower attached to the downstream section of the tunnel. The air is drawn through the tunnel and discharged to ambient. To control the wind velocity, a simple blockage device consisting of a flat piece of aluminum is used to cover the discharge chute of the blower. This allows the output area to be varied, which enabled us to vary the flow rate from 500 cfm to 0.0 cfm. From conservation of mass, $\dot{m}_{in}=\dot{m}_{out}$, where $\dot{m}$ is the mass flared and $\dot{m}=\rho AV$. Assuming that the flow is incompressible, $\rho_{in}=\rho_{out}$ and $A_{in}V_{in}=A_{out}V_{out}$.
Therefore:

$$Q=(AV)_{entrance}=(AV)_{exit} \tag{1}$$

Q=Volumetric flow rate
A=Area
V=Velocity

From this equation it is seen that the tunnel is capable of velocities between 0.0 ft/s and 23.9 ft/s. Because the experiments are to be used to verify the computer code and the computer code analyzes turbulent flow, (natural atmospheric conditions), it is desirable to have turbulent flow in the wind tunnel. The range of velocities which would support turbulent flow can be calculated using the Reynolds number (Re), where:

$$Re=\frac{Ud}{\nu} \tag{2}$$

U=tunnel velocity,
d=tunnel diameter,
ν=kinematic viscosity.

The transition to turbulent flow in a pipe occurs when $Re \approx 2300$. For a wind tunnel of diameter 8" and $\nu=1.5723\times10^{-4}$ ft^2/s, the tunnel flow is turbulent for wind velocities of .54 ft/s and greater. The tunnel velocities chosen for this experiment were 5, 10, and 15 ft/s, which are well above the turbulent transition.

A single-card data logger was used for data acquisition. This data logger was used as an analog to digital interface device to convert the 0 to 5 volt analog signal of the sensor equipment to digital counts of 0 to 255. The logger was connected to a PC and, using a BASIC data acquisition code written by Kuntavanish[2] and modified by Vincens (Appendix B), was controlled to collect and store the data. Data was collected for temperature and humidity in the tunnel and the test chamber using two humidity and temperature transducers. These sensors measure humidity by detecting changes in the capacitance of a thin polymer film as it absorbs moisture (Appendix A). The sensor for tunnel humidity and temperature is located directly downstream of the test chamber, and the sensor for the test chamber is inserted in the back wall of the chamber. The output of these transducers is in milliamps, so a circuit was designed and constructed by Vincens which is capable of converting the transducer output from current to voltage, enabling the data logger to read the analog voltage and convert it to a digital signal which is read and stored by the PC. Chamber overpressure and the tunnel wind velocity are measured using 2 differential pressure transducers. These sensors use a variable capacitance to measure pressure in the range of 0 to 0.5 inches of water, guage (iwg) (Appendix A).

Fabrics with a variety of properties were tested to determine the effects of a wide range of physical properties on the infiltration rate. To reduce the chance of error, more than one sample of each fabric was tested multiple times to verify that the data collected was dependent on the fabric properties, not the fabric sample, and independent of ambient room changes.

Experimental Procedures

Initially, fabric samples to be tested are prepared by drying a 5-inch diameter swatch with a heater to remove any excess moisture from the fabric. It is then placed in a sealed bag to allow the sample to reach ambient air temperature without absorbing excess moisture from the ambient air. Concurrently, flow in the wind tunnel is begun to remove any residual moisture from the tunnel, test chamber, and sensors, and is allowed to reach equilibrium for the temperature and humidity inside and outside the chamber. After the tunnel and sample reach equilibrium, the fabric sample is placed over the open end of the test chamber and a hose clamp is fastened around the outside to hold the fabric in place as shown in Figure 2. The chamber is then placed in the tunnel immediately downstream of the flow meter and the tunnel sections are bolted together. If an overpressure is desired for a particular test, the pressurizing air is turned on and the flow rate is adjusted to a value which supplies a much greater pressure than required for the experiment. This is to prevent the mass transport process from beginning before data is collected. If no overpressure is desired, a clamp is attached to the pressure line to prevent any unwanted leaks out of the test chamber through the line. Leaks would cause erroneous results because the transport is no longer taking place into a sealed chamber.

Once the tunnel is bolted together, the blower is turned on to return the sensors to ambient conditions. When these conditions are met, the humidifier is attached to the upstream flow inlet and is turned on. The data acquisition devices are then turned on and the chamber overpressure is adjusted to provide the desired pressure.

The test is allowed to run until the humidity and temperature inside the chamber vary little with time. Each test takes approximately one hour to reach this criteria. Once steady state has been reached, the data collection is stopped and the humidifier is removed from the inlet. The apparatus is allowed to continue running without the humidity to allow the conditions in the chamber to return to ambient conditions.

The data is stored on a PC in ASCII data file format. It is then imported to a spreadsheet and the relative humidity is normalized and plotted. The following equation is used for normalization:

$$NRH=\frac{RH_c-RH_{co}}{RH_t-RH_{co}} \tag{3}$$

where RH_c and RH_t are the relative humidities of the chamber and tunnel respectively, and RH_{co} is the initial chamber humidity. The normalized relative humidity (NRH) is then plotted vs. time. The information obtained from this graph is the infiltration of relative humidity into the chamber as a percentage of the tunnel relative humidity. The initial chamber humidity is subtracted in the normalization equation in order to provide NRH values from 0.0 to 1.0.

Computer Model

A major goal for development of this experimental apparatus was to provide data to validate a theoretical model. This model is to be used to assist in the improvement of the habitability of tentage structures. The computer model has been developed to model axisymmetric moisture transfer through the walls of a tentage structure which is subjected to either turbulent or laminar flow across its exterior and varying internal overpressure. The method used by this program is called "Semi-Implicit Method for Pressure Linked Equations-Revised," or SIMPLER. The FORTRAN code for this algorithm employs finite difference methods and has been adapted to this application by Robertson.[3] Currently, Robertson is developing an algorithm utilizing finite difference methods that will allow greater resolution and broader applications for the model, including three-dimensional laminar and turbulent flow.

Discussion/Results

The process of transport through fabrics occurs as a combination of several different mechanisms. The most prominent path of infiltration is through the interyarn spaces. This mechanism describes transport through the gaps between the individual yarns which comprise the fabric. These gaps are the result of the weaving process, and are thus a function of the type of weave used for the particular fabric. These spaces between the yarns are calculated as a void volume fraction and are a percent of the entire volume of the fabric. Transport in this manner occurs in two directions, along the fibers, and across the fibers. The spaces between the yarns which allow these types of diffusion are shown in the Scanning Electron Microscope (SEM) photographs of polyester duck (TEMPER tent fabric) displayed in Figures 3 and 4. The photos clearly show the gaps between individual fibers. Another method of infiltration is absorption of the moisture by the threads, wicking of the moisture along the thread, and then desorption of the moisture. The last method of transport is through the intrayarn spaces, which describes infiltration through the gaps within the individual threads which compose each strand of yarn as seen in Figures 5 and 6. These are photographs of a single yarn from a piece of polyester duck. The individual fibers shown form one strand of yarn, which is then woven with similar strands to form the polyester duck fabric.

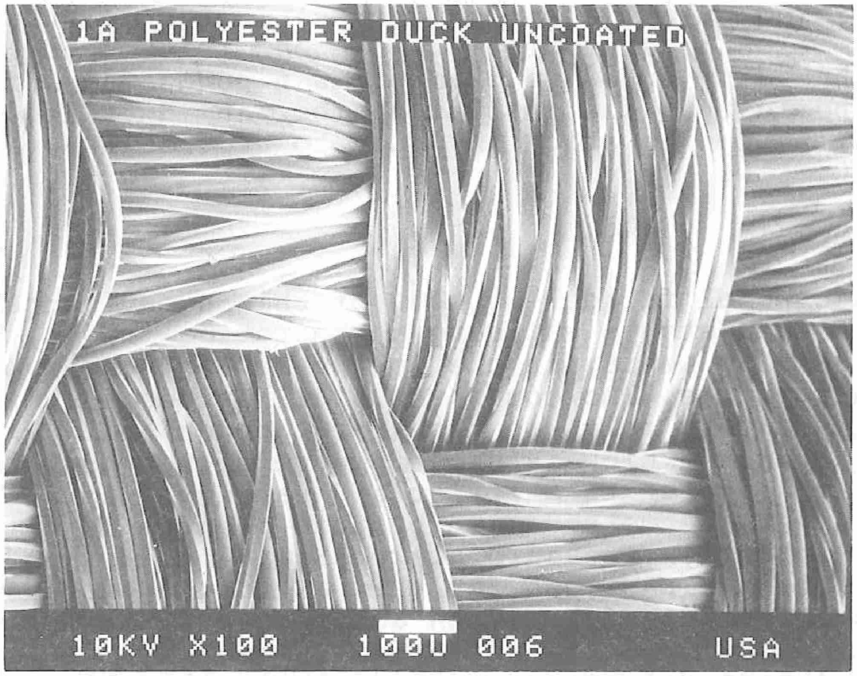

Figure 3: SEM photograph of polyester duck displaying interyarn spaces. (mag. x100)

The fabrics tested in this experimental apparatus, uncoated cotton duck, cotton oxford, and uncoated polyester duck tent fabric, were selected in order that a wide range of material properties were covered to determine factors that have a significant influence on the moisture transfer rate. The reason for choosing these fabrics is that their physical properties are readily available, which makes it easier to confirm the results of the computer model.

Cotton Duck

Cotton duck is made in different thread counts with 2-ply yarns of various sizes and weights. Some are woven with single yarns combined with ply yarns. The maximum air permeability of this cloth is 4.0 $ft^3/min/ft^2$ for a pressure difference across the fabric of 0.5 iwg.

Cotton Oxford

Cotton oxford is an oxford, "basket weave" fabric with two fine warp yarns and one filling yarn equal in size to the combined two warp yarns. The warp yarns are not twisted together but are two separate yarns woven as one. The maximum air permeability of the finished cloth is 20.0 $ft^3/min/ft^2$ (at 0.5 iwg) and the weight is within the range of 5.2 and 6.8 oz/yd^2.

Polyester duck

Polyester duck, or TEMPER tent fabric, is composed of fibers of polyethylene glycol terephtalate. (polyester) The maximum air permeability of this fabric is 1.0 $ft^3/min/ft^2$ (at 0.5 iwg), and its maximum weight is 13.5 oz/yd^2. Another relevant property is that it has a very small capacity to absorb moisture, as compared to the cotton fabrics.[4]

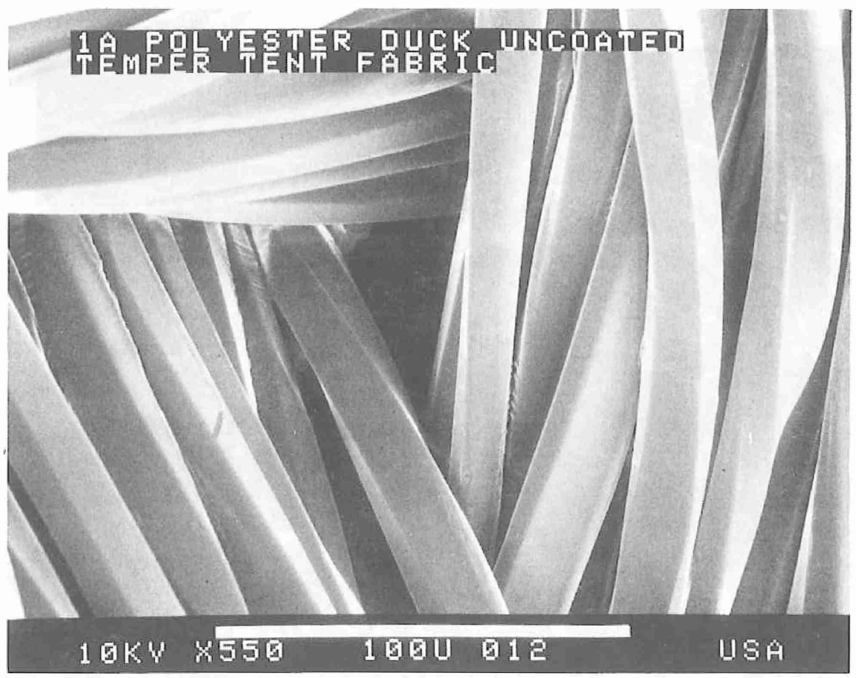

Figure 4: SEM photograph of polyester duck displaying interyarn spaces. (Mag. x550)

Figure 5: SEM photograph of a yarn of polyester duck showing gaps between fibers. (Mag. x45)

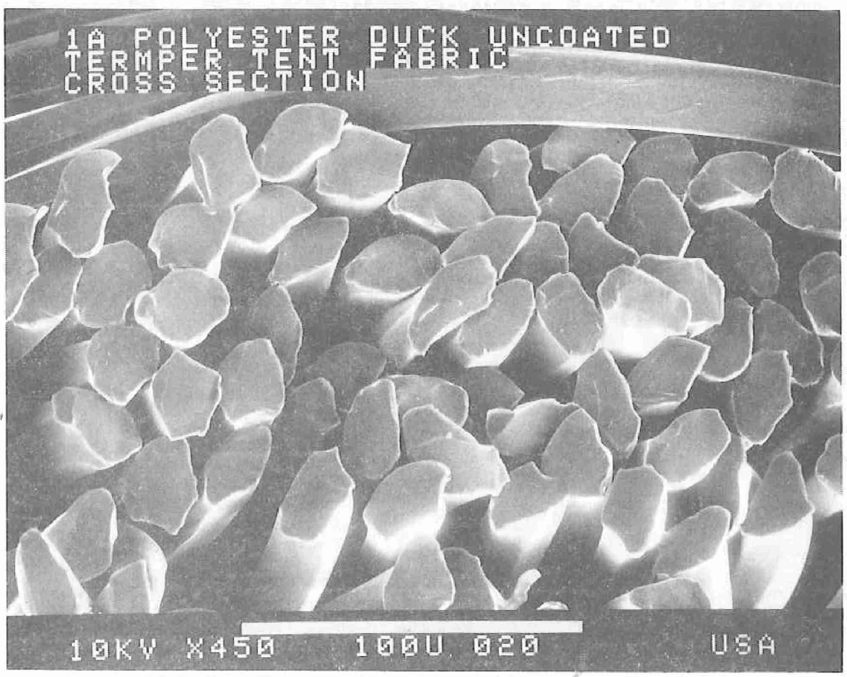

Figure 6: SEM photograph of a yarn of polyester duck showing gaps between fibers. (x450)

Discussion/Results (cont.)

The conditions varied during these experiments were the chamber overpressure, the external wind velocity, and the type of fabric used. Pressurizing the chamber creates a pressure gradient across the fabric that increases as the chamber pressure is increased. Since the air used to create the overpressure is dry air, this overpressurization also serves to supply a constant source of low-humidity air which will further decrease the overall humidity within the chamber.

Increasing the tunnel wind velocity has several effects on the moisture transfer rate. Since the vapor source is located 5 ft. upstream of the test chamber, there will be a slight decrease in the time it takes for the moisture to reach the chamber, which will be on the order of fractions of a second. This delay will not be discussed here as it is small compared to the other factors. The more significant effect of this increase in wind speed is to create a greater stagnation pressure on the outside of the fabric, which serves to force the moisture through the fabric at a higher rate.

When there is no overpressure within the chamber, the chamber pressure is equal to the stagnation pressure caused by the external flow encountering the fabric. This results in no pressure gradient across the fabric. In this case, the moisture vapor transfer into the chamber is the result of natural convection through the pores in the fabric and absorption/desorption by the fabric. Since there will be no pressure gradient across the fabric, regardless of the external wind speed, an increase in the tunnel wind speed has a negligible effect on the infiltration rate. Figures 7 and 8 display the minimal effect of an increase in wind speed on polyester duck and cotton oxford, respectively, under the case of no chamber pressurization.[5]

When the chamber is pressurized, an increase in tunnel wind speed has a much greater effect on the rate of transport into the test chamber. In this case, an increase in stagnation pressure upstream of the chamber corresponding to an increase in tunnel wind speed causes the rate of infiltration into the test chamber to be significantly increased. This is shown in Figure 9, which is a comparison of cotton duck and cotton oxford at several different conditions. Traces 2 and 3 in this Figure compare cotton duck at an overpressure of 0.15 iwg and tunnel wind speeds of 5 and 15 ft/s. In this case, the higher tunnel wind velocity results in a significantly increased transport rate.[6]

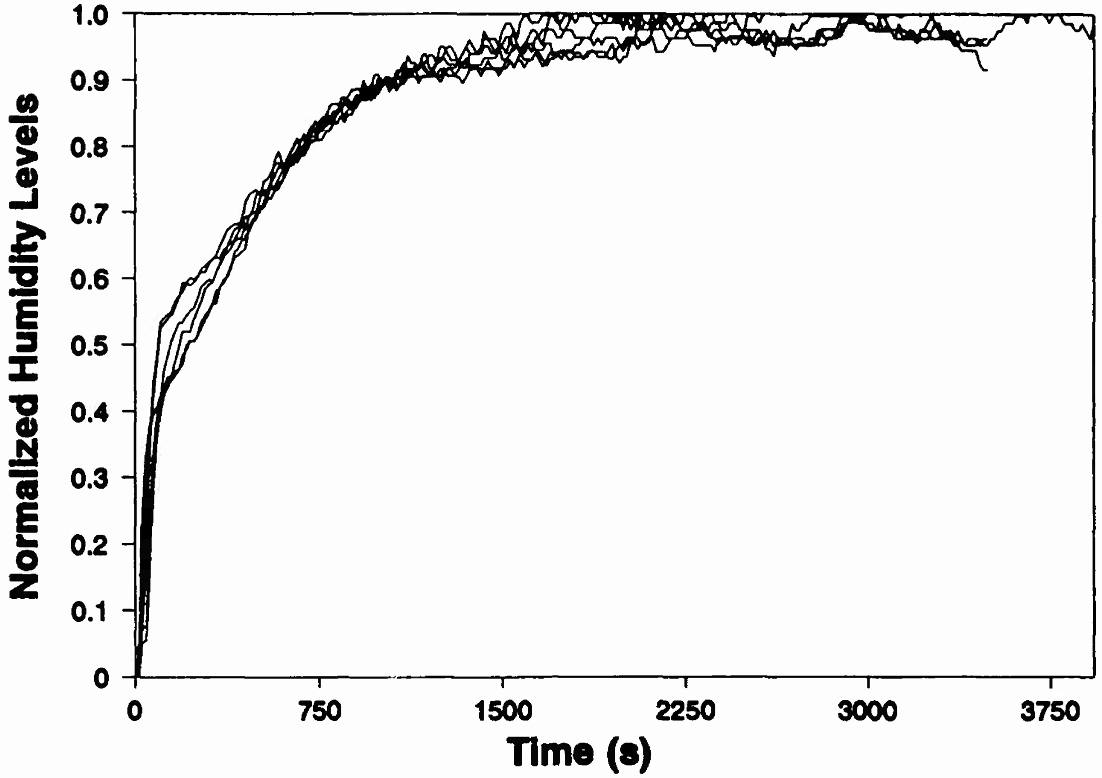

Figure 7: Humidity transfer through polyester duck; tunnel speeds of 5, 10 and 15 ft/s, 0 iwg chamber overpressure.

For a given set of conditions, a more permeable fabric will have a higher infiltration rate than a less permeable fabric with the same weave type. This relationship is not linear, and depends heavily on the dominant mode of infiltration involved for the particular fabric. An example of this can be seen in the comparison of cotton duck and cotton oxford in Figure 8. Although identical conditions were used for each fabric, the cotton duck, which is much thicker and heavier, had a much lower infiltration rate. The two traces for each fabric in Figure 7 indicate tunnel wind speeds of 5 and 10 ft/s, with neither fabric showing significant variance as a result of the different wind speeds, as is expected in the case of no chamber overpressure.

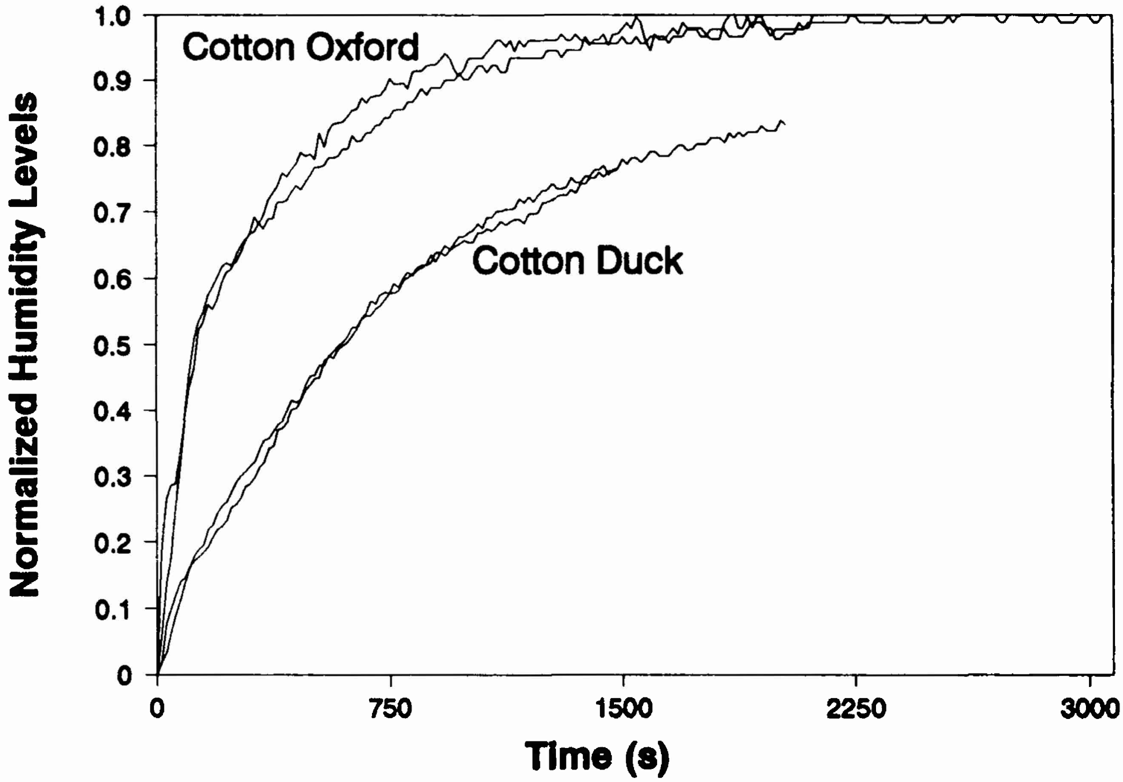

Figure 8: Humidity Transfer through cotton oxford and cotton duck with tunnel speeds of 5, 10 ft/s and 0 iwg chamber overpressure.

A factor which has not yet been included in processing the experimental data is the effect of the temperature change in the tunnel during the test. This change in temperature is caused by evaporative cooling, which occurs when air is brought in contact with a water source at a temperature equal to the wet bulb temperature of the air. As the heat of the air vaporizes the water, the dry bulb temperature of the air is lowered. During this process the wet bulb temperature remains constant and the dewpoint temperature, relative humidity and specific humidity increase. This decrease in dry bulb temperature means that if the amount of moisture within the chamber remains constant throughout the test, the results will actually show an increase in the chamber relative humidity.[7]

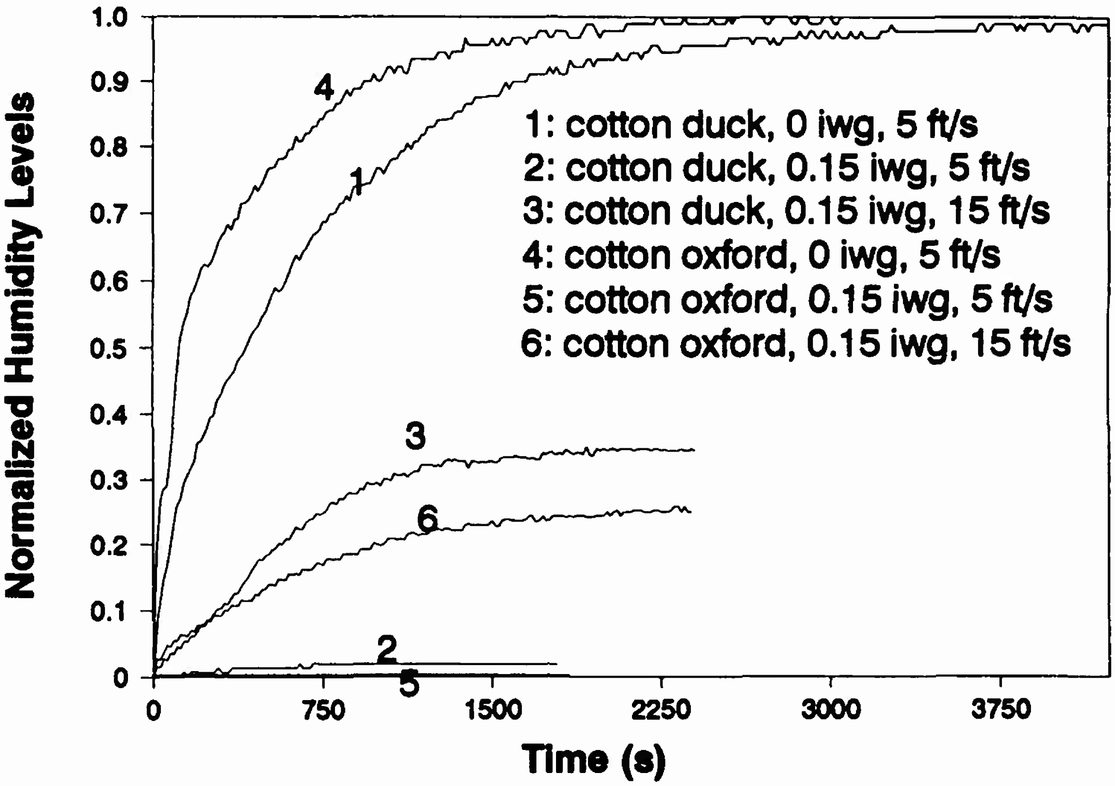

Figure 9: Humidity transfer rates for cotton duck and cotton oxford for various wind speeds and chamber overpressures.

Conclusions and Recommendations

Conclusions

The conclusions which can be drawn from this experiment are:

- An apparatus has been developed capable of analyzing fabric properties under a variety of conditions.
- The effect which the external wind speed has on the moisture transfer rate is dependent on the internal overpressure. A higher overpressure results in a greater dependence of the moisture vapor transfer rate on the wind speed.
- At low or no overpressures, small increases in the level of pressurization result in a large decrease in the humidity level inside the tent.
- The fabric weight, weave type, and absorbency of the fibers are all significant factors in decreasing the moisture vapor transfer rate.

Recommendations

In order to more accurately examine this process, several steps are recommended:

- Improvements on the 2-dimensional wind tunnel apparatus to increase accuracy and widen the range of possible test conditions. Possible improvements would include:
  a) A more accurate data acquisition system, as the current Tattletale board is at times unreliable and difficult to manage.
  b) More accurate humidity sensors. The sensors currently being used do not give equal readings when subjected to identical conditions, which has been corrected in the data acquisition software for these experiments, but are not as accurate as would be desired. The current sensors do maintain a constant ratio as the relative humidity is changed.
  c) In-depth comparisons of the experimental results with the theoretical model in order to determine the level of correlation between them.
  d) Testing on scale tent models in the environmental chambers in order to gain initial data on moisture vapor transmission in 3-dimensional cases, which will then be compared to the 2-dimensional data to see if better information on the fabrics can be obtained.
  e) Improvements on the doors and windows in the room containing the experimental apparatus should be made so that the ambient humidity and temperature in the room are held at a more constant level.

This document reports research undertaken at the U.S. Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-92/031 in the series of reports approved for publication.

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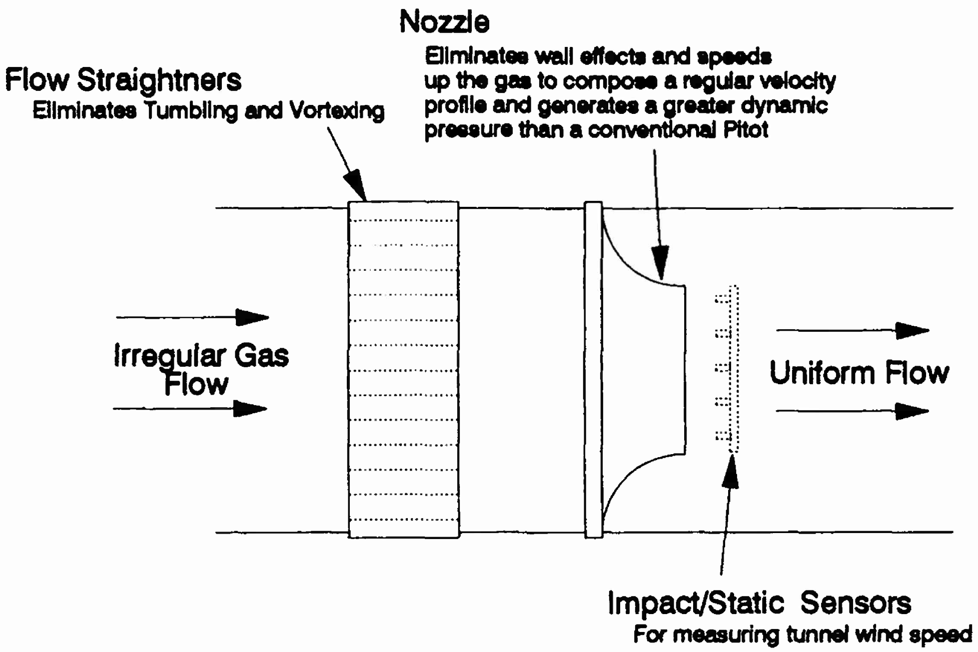
Appendix A:
Flow Meter
Humidity/Temperature Sensors
Pressure Transducers
Data Logger

Flow Meter



Humidity/Temperature Sensors

Temperature

Range:	-40 to 80°C
Span adjustment:	120°C max. 50°C min.
Factory setting:	100°C
Accuracy at 20°C:	±0.3°C
Typical Temperature Dependence of electronics:	±0.02°C/°C
Output Signals:	4 to 20 mA
Sensor:	Pt 100 RTD 1/3 DIN 43760 B
Filter:	18.5 mm Diameter 0.1 micron membrane filter

Pressure Transducers

Pressure Ranges

Unidirectional	0.0 to 0.5 in. H_2O
Max. line pressure	14.0 in. H_2O Gage
Overpressure	10.0 in. H_2O

Accuracy Data

Accuracy	$<\pm 1.0\%$ full scale (best straight line); combines non-linearity, hysteresis, and non-repeatability.
Resoloution	Infinite
Repeatability	$<\pm 0.3\%$
Thermal Effects	$<\pm 0.333\%$FS/°F over 40°F to 100° F ranges. Calibrated at 70°F.

Data Logger

Specifications:

Language:	TTBASIC
Interface:	16 I/O lines 11 chan, 10 bit A-D Hardware UART
Regulator:	7-15V input 5.0V $\pm 3\%$ out
Total RAM:	32K
Program \\ Variables> Datafile/	28K divided between these three memory locations.
Misc:	4K

Appendix B

Data Acquisition and Storage Code

Data Acquisition and Storage Code

```
10     DIM C(10),C$(10),D(10,800),T$(800)
15     SCREEN 0 : CLS
25     REM DT=1
100    REM **** DATA ACQUISITION PROGRAM FOR MOISTURE TRANSFER
       EXPERIMENT
10000 LOCATE 4,10
10010 PRINT "DATA ACQUISITION PROGRAM FOR MOISTURE TRANSFER
      EXPERIMENT"
10020 LOCATE 8,10: INPUT "DATE MO-DATE-YR (DEC-31-87):",D$
10030 LOCATE 10,10:INPUT "RUN NUMBER :",R$
10035 LOCATE 12,10:INPUT "TYPE OF FABRIC (COTTON DUCK):",F$
10055 LOCATE 18,10:INPUT "DATA TO BE TAKEN AT 30 SEC INTERVALS
(Y/N)";Y$
10056 DT=30
10057 IF INSTR(Y$,"Y") THEN GOTO 10060
10058 LOCATE 19,10:INPUT "NEW TIME INTERVAL (SECONDS)";DT
10060 LOCATE 20,20:PRINT "                                     "
10070 LOCATE 20,20:PRINT "PLUG IN TATTLETALE AND WAIT 1 SECOND"
10071 FOR I=1 TO 100
10072 NEXT I
10160 LOCATE 22,20:PRINT "TO BEGIN, RUN HIT RETURN <>"
10170 K$=INKEY$:IF K$<>"" THEN GOTO 20000 ELSE GOTO 10060
11080 REM ***********************
11090 REM
12000 REM **** VARIABLE NAMES****
12010 REM  VARIABLE D(1,T) IS THE CHAMBER PRESSURE
12020 REM  VARIABLE D(2,T) IS THE TUNNEL HUMIDITY
12025 REM  VARIABLE D(3,T) IS THE TUNNEL WIND SPEED
12030 REM  VARIABLE D(4,T) IS THE TUNNEL TEMPERATURE
12040 REM  VARIABLE D(5,T) IS THE CHAMBER HUMIDITY
12050 REM  VARIABLE D(6,T) IS THE CHAMBER TEMPERATURE
12080 REM
12090 REM ***********************
20000 CLS
21000 REM ***********************
21100 REM ****CONSTANTS**********
22050 T=0
22100 T(0)=T
22200 TM=T
30000 SCREEN 2 : CLS
30100 WINDOW (-1000,-50)-(11700,190)
30200 LINE (0,-5)-(0,105)
30300 FOR I=1 TO 10
30400 LINE (-50,I*10)-(50,10*I)
30500 NEXT I
30600 LINE (-200,0)-(11000,0)
30700 FOR I=1 TO 6
30800 LINE (I*1800,-2)-(I*1800,2)
30900 NEXT I
31000 FOR I=0 TO 100 STEP 10
```

```
31100 IF I<=90 THEN LOCATE 20-I/10,3
31200 IF I=100 THEN LOCATE 20-I/10,2
31300 PRINT I
31400 NEXT I
31500 FOR I=0 TO 6
31600 X=I*1800/158.75
31700 L=CINT(X)
31800 LOCATE 21,6+L:PRINT I*30
31900 NEXT I
32000 LOCATE 13,1:PRINT "%"
32100 LOCATE 14,1:PRINT "R"
32200 LOCATE 15,1:PRINT "H"
32300 LOCATE 22,25: PRINT "NUMBER OF DATA POINTS TAKEN"
32400 REM PRINT TAB DATA
32500 FOR I=0 TO 4 STEP 2
32600 LOCATE 3+I,1:PRINT "T          ";"   TEMPT= ";"    ";"
      TEMPC=  ";
32700 PRINT "    ";"  VELOCITY=";"    ";"  P=";"          "
32800 LOCATE 4+I,15:PRINT "RHT =";"    ";"          ";"    ";"
      RHC ="
32900 NEXT I
33000 LOCATE 23,5:PRINT "TO END, HIT RETURN <>"
40000 TIME$="00:00:00"
40010 OPEN "COM1:9600,N,8,1,RS" AS #1
40020 REM OPEN "SCRN:"FOR OUTPUT AS #3
40025 GOTO 50000
40030 CLOSE #1
40035 OPEN "COM1:9600,N,8,1,RS" AS #1
40037 PRINT #1,"RUN"
40040 B$=""
40050 IF EOF(1) THEN 40050
40060 A$=INPUT$(LOC(1),#1)
40070 B$=B$+A$
40080 FOR W=1 TO 10:NEXT W
40090 IF LOC(1)>0 THEN GOTO 40060
40100 LP=0
40110 FOR F=1 TO 6
40120 LP=LP+1
40130 E$=MID$(B$,LP,1)
40140 IF ASC(E$)=75 THEN GOTO 40170
40150 C$=C$+E$
40160 GOTO 40120
40170 C(F)=VAL(C$)
40180 C$=""
40190 NEXT F
40300 T$(T)=TIME$
40400 REM INPUT#1,C(1),C(2),C(3),C(4),C(5),C(6)
40750 K$=INKEY$:IF K$<>"" THEN GOTO 61000
40760 REM NEXT I
40800 REM PRINT "T=";T,"TIME";TIME$
40900 REM PRINT USING "###";A,B,C,D,E,F
41000 D(1,T)=.12098*(C(3))-.12 : REM CHAMBER PRESSURE
```

```
41100 D(2,T)=.363*(C(2))-13.9 : REM TUNNEL HUMIDITY
41200 D(3,T)=SQR(C(1)*8.47)/2 : REM TUNNEL WINDSPEED
41300 D(4,T)=.639*(C(4))-14 : REM TUNNEL TEMP
41400 D(5,T)=.363*(C(5))-14 : REM CHAMBER HUMIDITY
41550 D(6,T)=.639*(C(6))-16 : REM CHAMBER TEMP
41800 IF T>=1 THEN LINE((T-1)*DT,D(2,T-1))-(TM,D(2,T))
42000 CIRCLE(TM,D(5,T)),50
42100 K$=INKEY$:IF K$<>"" THEN GOTO 61000
43000 FOR I=0 TO 4 STEP 2
43110 LOCATE 3+I,1 :PRINT"      "
43111 LOCATE 3+I,20:PRINT"     "
43112 LOCATE 3+I,20:PRINT"     "
43113 LOCATE 3+I,35:PRINT"     "
43114 LOCATE 3+I,48:PRINT"     "
43115 LOCATE 3+I,58:PRINT"     "
43116 LOCATE 4+I,21:PRINT"     "
43117 LOCATE 4+I,33:PRINT"     "
43118 LOCATE 4+I,45:PRINT"     "
43120 NEXT I
43400 FOR I=0 TO 4 STEP 2
43410 IF T>=2 THEN GOTO 43490
43420 IF T=0 THEN I=4
43425 IF T=0 THEN K=0
43430 IF T=1 AND I<=2 THEN I=2 ELSE I=I
43490 K=(4-I)/2
43510 LOCATE 3+I,2 :PRINT T$(T-K)
43511 LOCATE 3+I,21:PRINT USING "##.#";D(4,T-K)
43512 LOCATE 3+I,36:PRINT USING "##.#";D(6,T-K)
43513 LOCATE 3+I,48:PRINT USING "##.#";D(3,T-K)
43515 LOCATE 3+I,59:PRINT USING "#.###";D(1,T-K)
43516 LOCATE 4+I,21:PRINT USING "##.#";D(2,T-K)
43518 LOCATE 4+I,50:PRINT USING "##.#";D(5,T-K)
43600 NEXT I
44000 T=T+1
44340 REM LOCATE 3+I,6 :PRINT "      "
45000 TM=T*DT
46000 GOTO 40040
50000 PRINT #1, "5 FOR A=0 TO 5"
50010 PRINT #1, "10 PRINT CHAN(A);"
50020 PRINT #1, "20 PRINT \75;"
50030 PRINT #1, "30 NEXT A"
50040 PRINT #1, "40 PRINT"
50050 PRINT #1, "60 GOTO 5"
50060 PRINT #1, "50 SLEEP 1500"
60000 GOTO 40030
61000 CLOSE #1
61050 LOCATE 23,5: PRINT "                                 "
61100 LOCATE 23,5:PRINT" RUN COMPLETED! UNPLUG TATTLETALE."
61200 LOCATE 23,40:INPUT "SAVE TO FILE (Y) OR END (E)";S$
61400 SCREEN 0 : CLS
61450 IF INSTR(S$,"E") THEN GOTO 65000
61500 LOCATE 17,10:PRINT "SAVING FILE:";"C:F"+R$
```

```
61700 OPEN "O",#2,"C:F"+R$
61710 PRINT #2,D$;",";R$;",";F$;",";T,DT
61750 COUNT=0
61800 FOR I=0 TO T
61850 PRINT#2,T$(I);",";;COUNT;D(1,I);D(2,I);D(3,I);D(4,I);
      D(5,I);D(6,I)
61860 COUNT=COUNT+15
61900 NEXT I
61950 CLOSE #2
62000 CLS
62200 LOCATE 15,10:INPUT"RERUN (R) OR END (E)";S$
62300 IF INSTR(S$,"R") THEN GOTO 15
62400 IF INSTR(S$,"E") THEN GOTO 65000
65000 SCREEN 0:END
```

Appendix C

Experimental Data

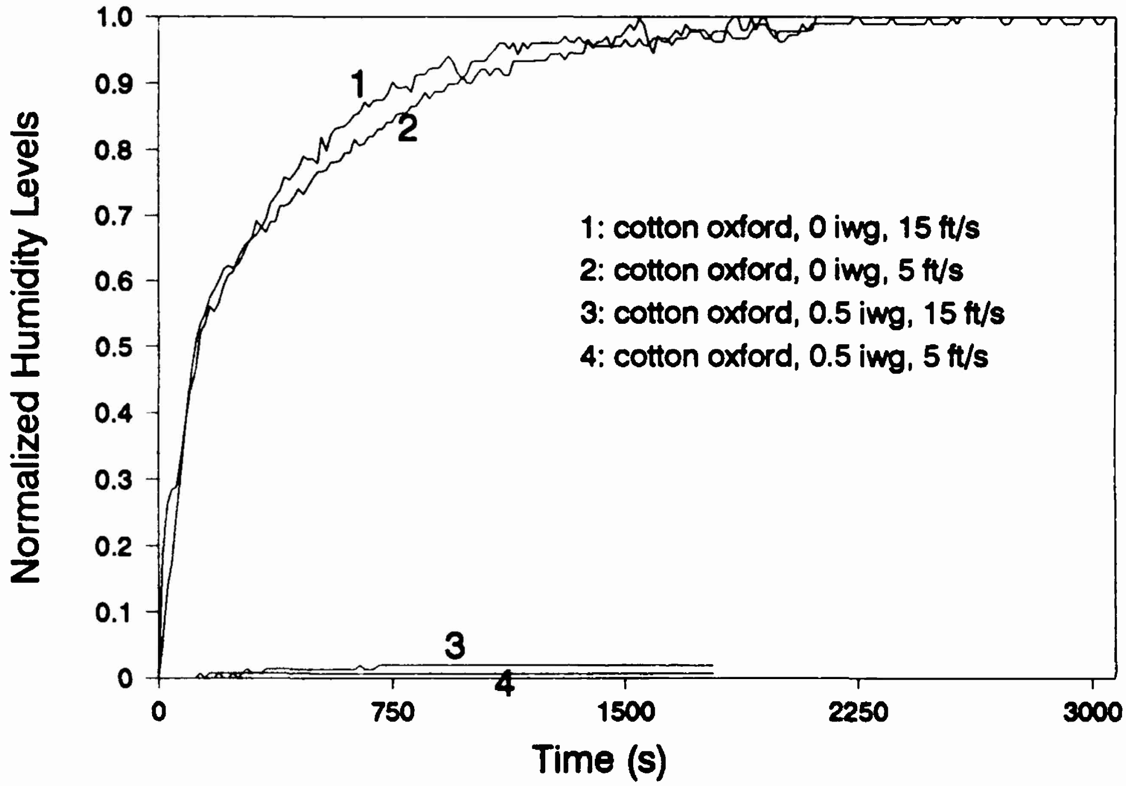


Figure C1. Cotton oxford with 0.0 & 0.5 iwg overpressure and 5 & 10 ft/s tunnel windspeeds.

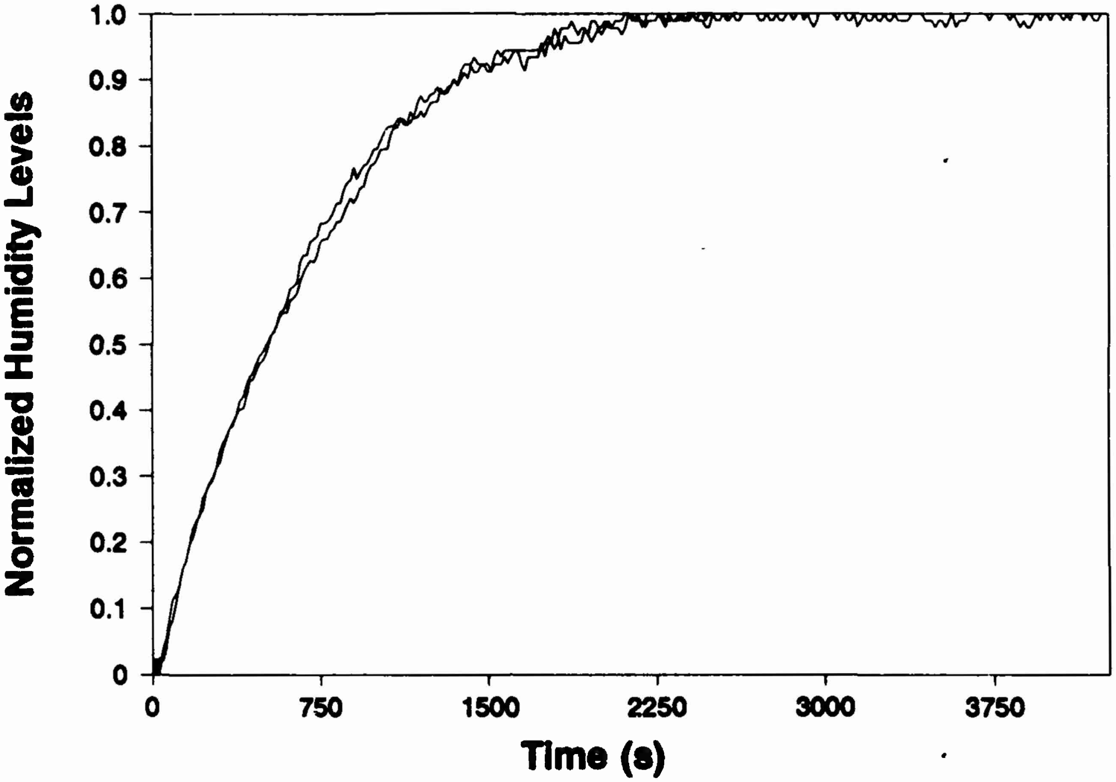


Figure C2. Cotton duck, 0 iwg overpressure at tunnel speeds of 5 & 10 ft/s.

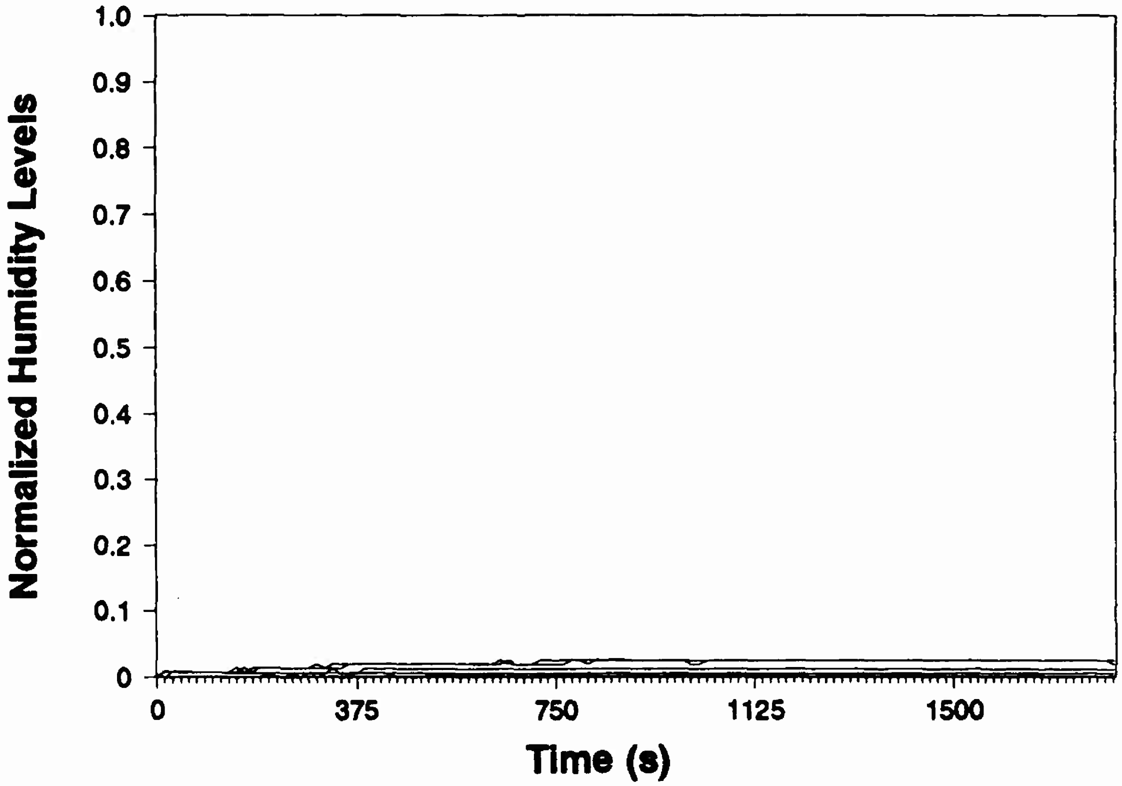


Figure C3. Cotton Oxford; 0.5 iwg overpressure and tunnel speeds of 5, 10 and 15 ft/s.

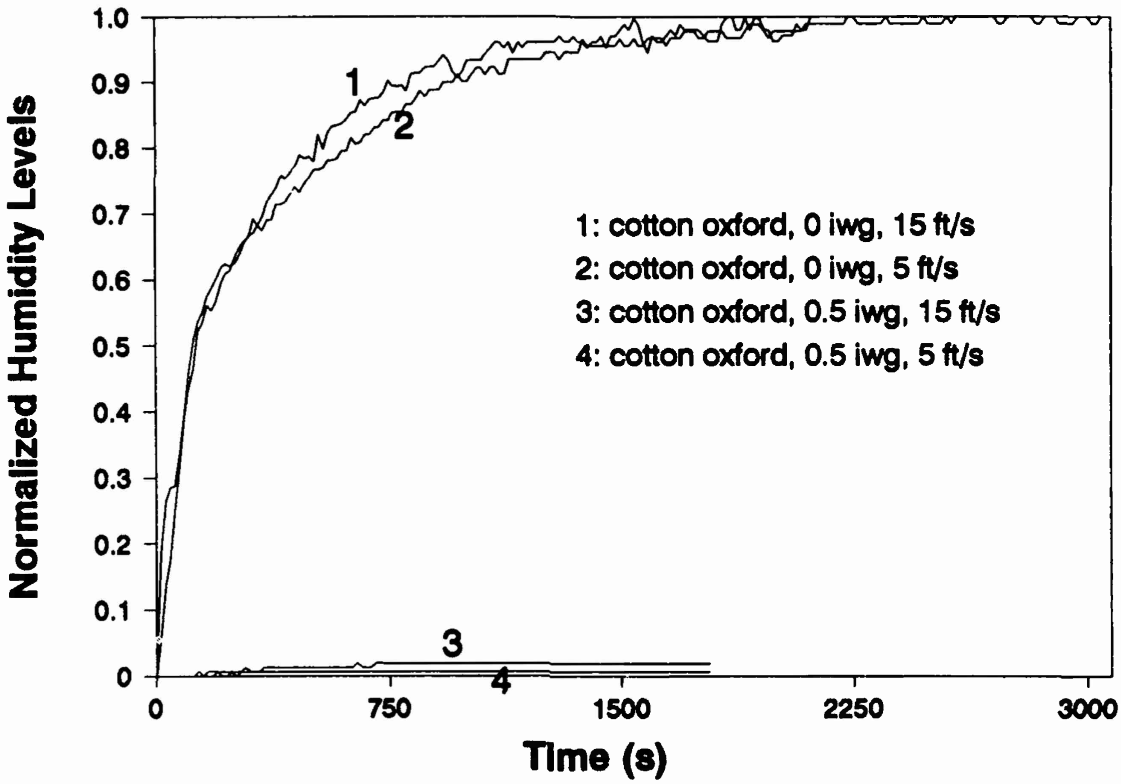


Figure C4. Cotton Oxford at 0 & 0.5 iwg overpressure and 5 & 15 ft/s tunnel windspeeds.

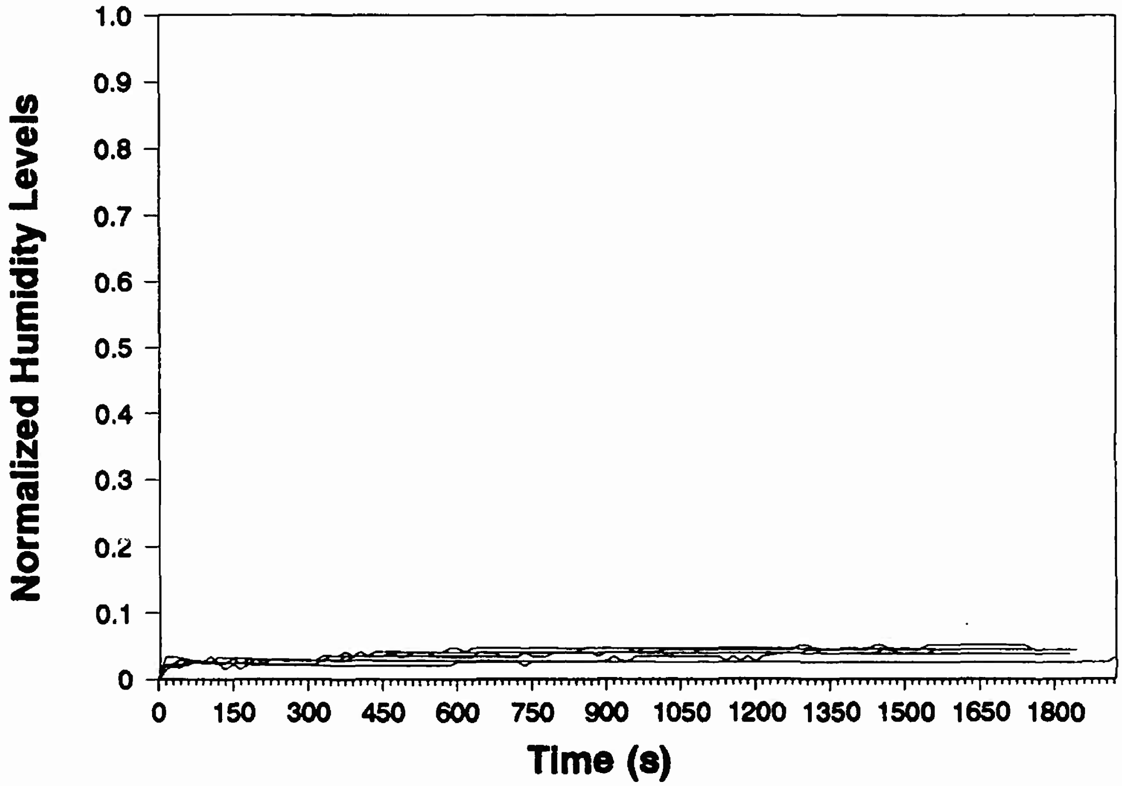


Figure C5. Polyester duck, 0.5 iwg overpressure and 5, 10 & 15 ft/s tunnel windspeed.